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Signed

Dated 12 May 2004

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11APR03 E797523-1 C70137
P01/7700 0.00-0308343.3

1/77

Request for grant of a patent

(See the notes on the back of this form. You can also get an explanatory leaflet from the Patent Office to help you fill in this form)

The Patent Office

Cardiff Road
Newport
South Wales
NP10 8QQ

1. Your reference

2. Patent application number *(The Patent Office will fill in this part)*
   0308343.3   10 APR 2003

3. Full name, address and postcode of the or of each applicant *(underline all surnames)*
   UNIVERSITY COLLEGE LONDON
   GOWER STREET
   LONDON. WC1E 6BT

   Patents ADP number *(if you know it)*
   7986520002

   If the applicant is a corporate body, give the country/state of its incorporation

4. Title of the invention
   ATHERMALISATION OF TUNEABLE LASERS

5. Name of your agent *(if you have one)*
   DR. STEVEN SCHOOLING

   "Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*
   UCL BUSINESS
   BROOK HOUSE
   2-16 TORRINGTON PLACE
   LONDON. WC1E 7HN

   Patents ADP number *(if you know it)*
   8608598001

6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and *(if you know it)* the or each application number

Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application

Number of earlier application	Date of filing *(day / month / year)*

8. Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if:*
   a) any applicant named in part 3 is not an inventor, or
   b) there is an inventor who is not named as an applicant, or
   c) any named applicant is a corporate body.
   See note (d))

9. Enter the number of sheets for any of the following items you are filing with this form. Do not count copies of the same document

Continuation sheets of this form	—
Description	5
Claim *(s)*	2
Abstract	1
Drawing *(s)*	5+5

10. If you are also filing any of the following, state how many against each item.

Priority documents	—
Translations of priority documents	—
Statement of inventorship and right to grant of a patent *(Patents Form 7/77)*	—
Request for preliminary examination and search *(Patents Form 9/77)*	—
Request for substantive examination *(Patents Form 10/77)*	—
Any other documents *(please specify)*	—

11\. I/We request the grant of a patent on the basis of this application.

Signature [signature] Date 10.4.03.

12\. Name and daytime telephone number of person to contact in the United Kingdom Dr. Steven Schooling 020 7679 6338

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Notes

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f) For details of the fee and ways to pay please contact the Patent Office.

FIGURE 1

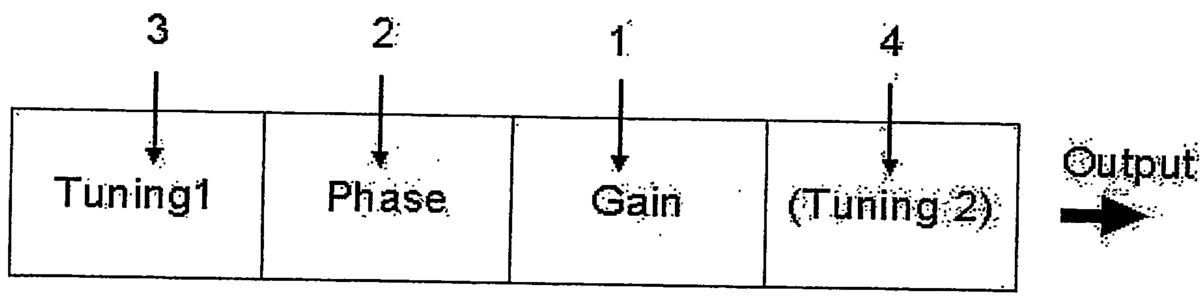
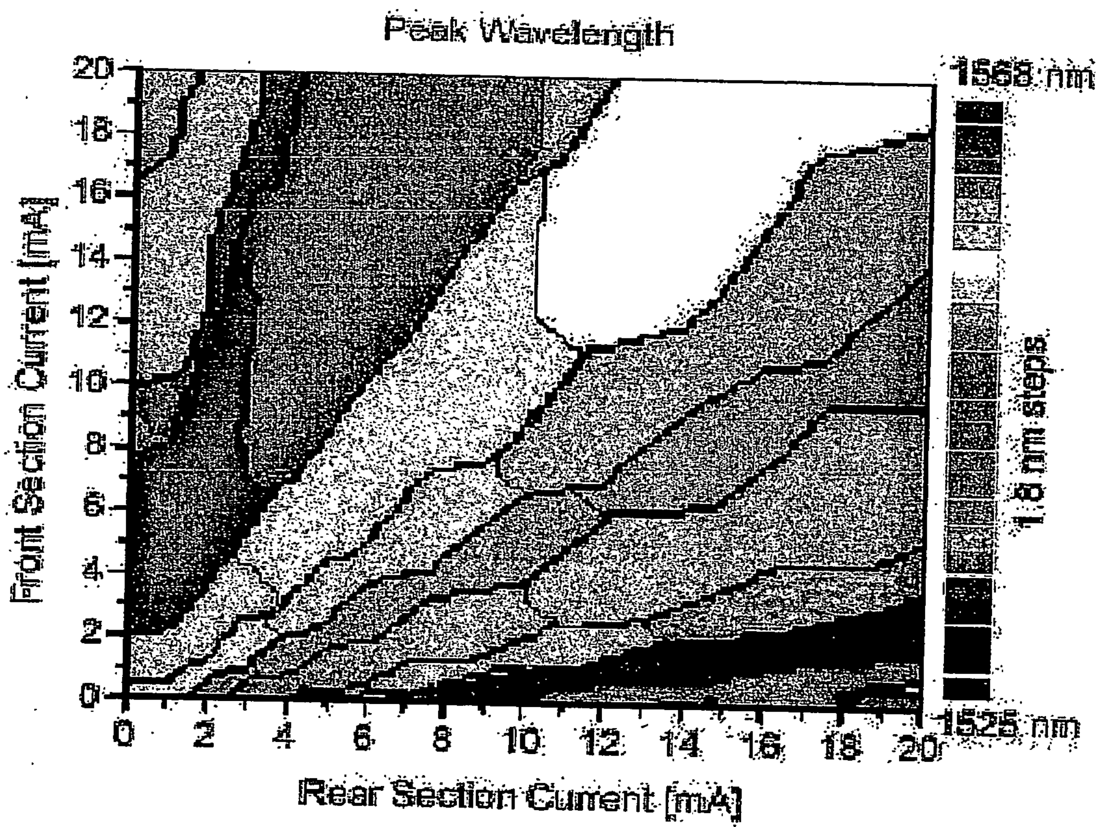
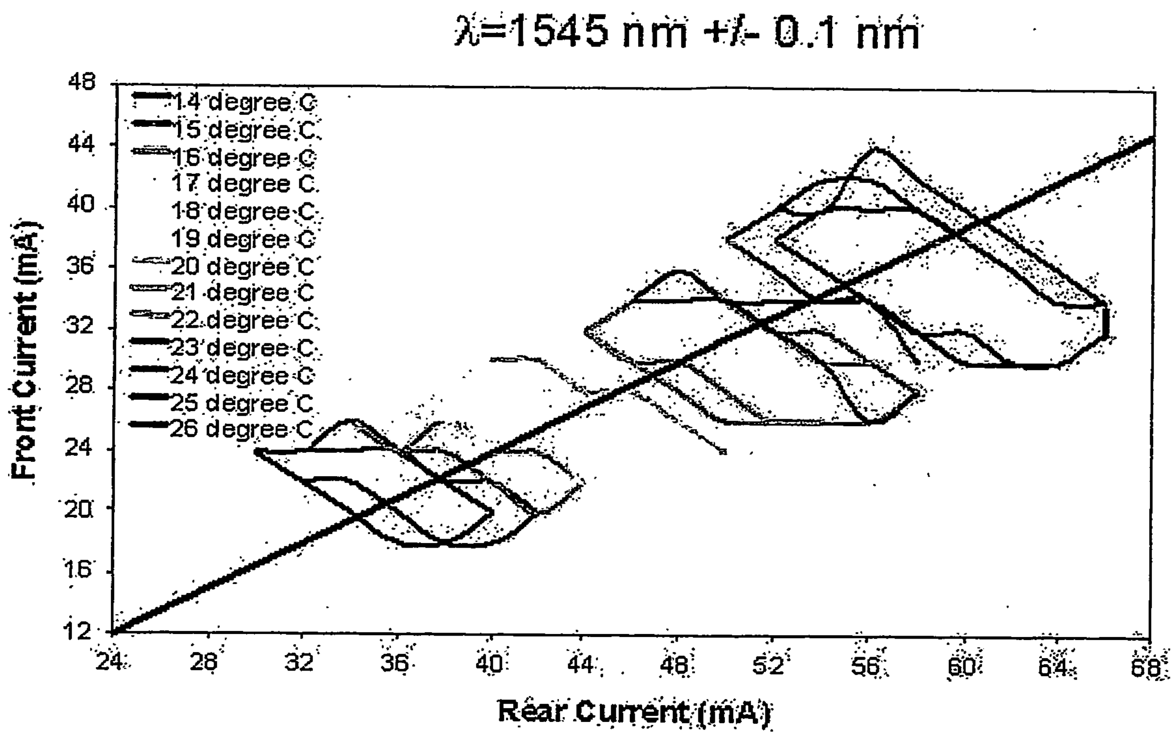


FIGURE 2



Peak Wavelength
Front Section Current [mA]
Rear Section Current [mA]
0
2
4
6
8
10
12
14
16
18
20
1568 nm
1.8 nm steps
1525 nm

FIGURE 3



λ=1545 nm +/- 0.1 nm
14 degree C
15 degree C
16 degree C
17 degree C
18 degree C
19 degree C
20 degree C
21 degree C
22 degree C
23 degree C
24 degree C
25 degree C
26 degree C
Front Current (mA)
Rear Current (mA)
48
44
40
36
32
28
24
20
16
12
24
28
32
36
40
44
48
52
56
60
64
68

FIGURE 4

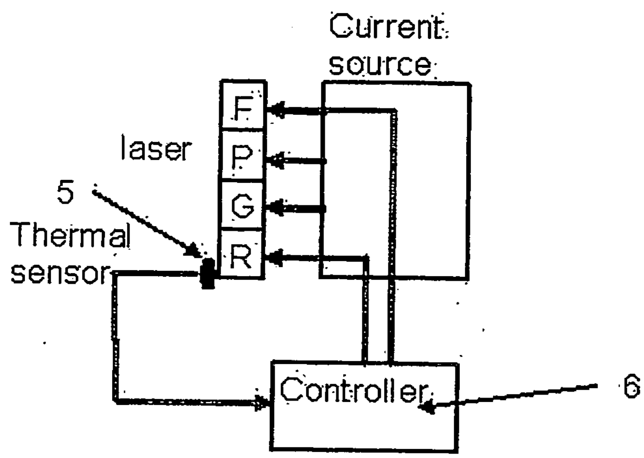


FIGURE 5

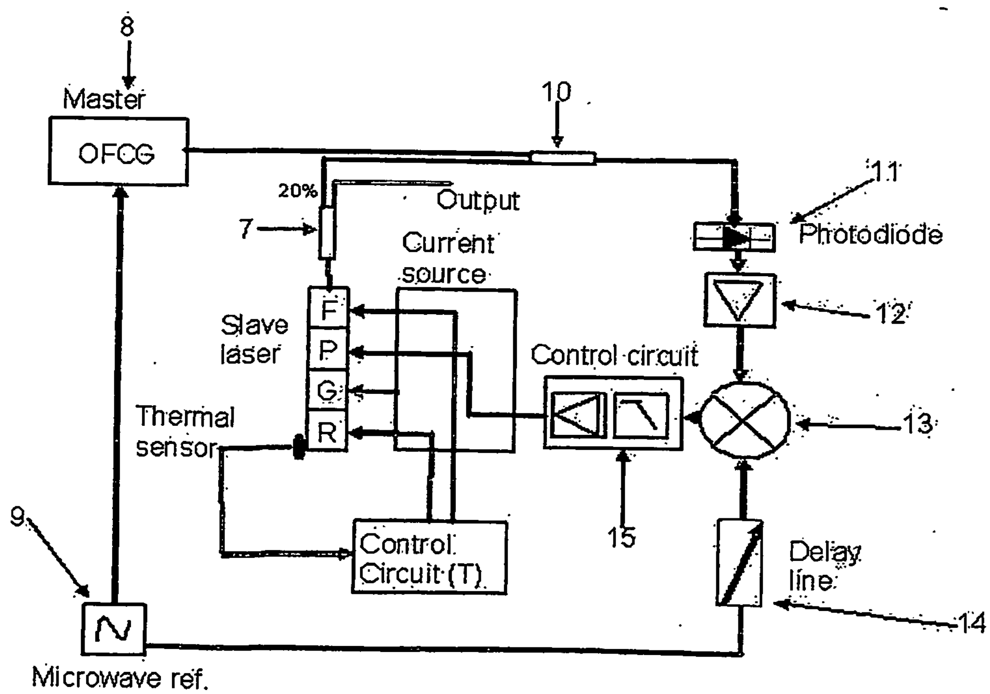
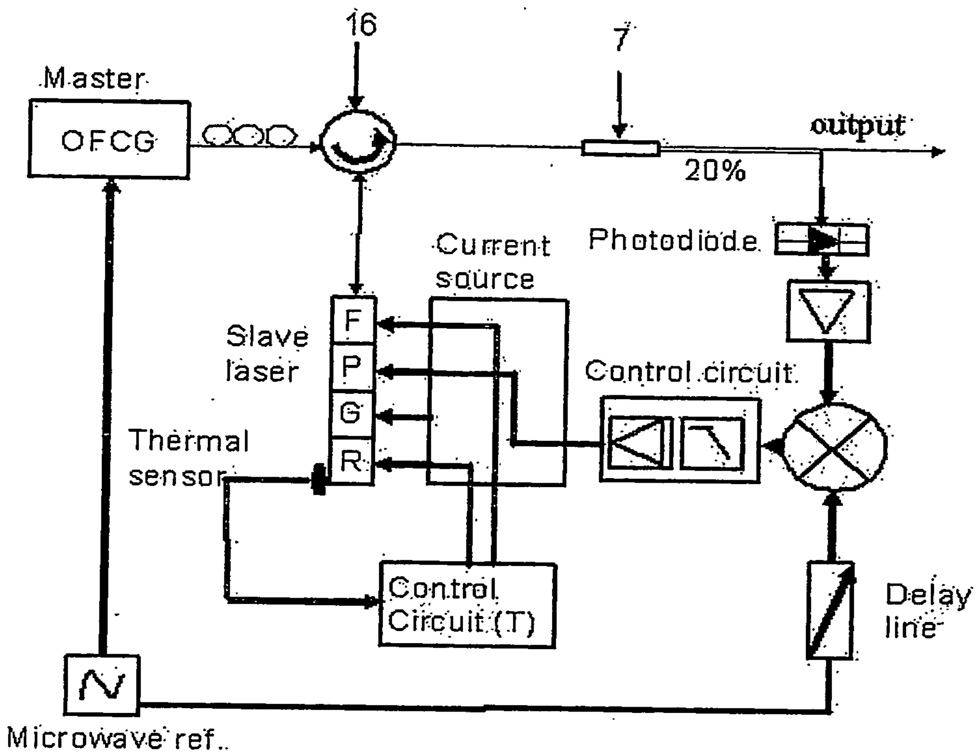


FIGURE 6


16
7
Master
OFCG
output
20%
Photodiode
Current source
Slave laser
F
P
G
R
Control circuit
Thermal sensor
Control Circuit (T)
Delay line
Microwave ref.

ATHERMALISATION OF TUNEABLE LASERS

This invention describes a method and system to obtain stable output wavelength from tuneable laser diodes without the use of laser temperature control such as that provided by a thermo electric cooler control (TEC). In more detail, it relates to apparatus for compensating for the temperature dependence of the wavelength of a semiconductor laser, and the methods for using the apparatus to synthesize exact optical frequencies from a tuneable laser without any temperature control.

Fibre optic wavelength division multiplex (WDM) telecommunications networks require tuneable sources which can cover all the spectrum allowed. Such sources exist and offer tuneable (DBR -Distributed Bragg Reflector- or DFB –Distributed Feed Back-laser) or highly tuneable (SG-DBR –Sampled Grating- or SSG-DBR –Super Structure Grating-) output, however such applications should present good stability in wavelength. In current practice, this is provided by temperature control since the main cause of wavelength drift is variation in laser temperature as tuneable laser output wavelength is temperature dependent (typical coefficient: 0.1 nm/degree). The temperature is usually controlled by mean of a Peltier thermoelectric cooler. Such devices consume up to 10 W of electrical power, compared to of order of 0.2 W consumed by the laser. In large WDM systems with 50-200 channels the resultant prime power and cooling requirements are onerous. Furthermore, as laser diode operating temperature ranges are increased to from 0 to 85 degrees C, coolerless operation becomes very attractive for reduced cost and increased reliability.

This invention proposes a simple and effective scheme to obtain frequency stable laser operation without active laser temperature control. The method relies on sensing the chip temperature and relating it to the tuning section(s) electrical characteristics for a given optical frequency. By mapping the frequency interdependence of upto four parameters, the user can extract a simple relation between the different parameters involved. This relation is defined by the longitudinal mode jump (i.e. the output wavelength) boundaries within the mapping, which are temperature independent and the linear variation of the wavelength with temperature (~0.1nm/degree C). Therefore, one can program current/voltage controllers from a chip temperature reading obtained via a

temperature sensor (most commercial laser modules have an in-built temperature sensor) to give suitable values for the grating section current(s)/voltage(s) to obtain and thus maintain the wanted output frequency. The laser temperature is kept within its allowed maximum limit using conduction transfer through the package and normal equipment cooling.

This invention can also be associated with prior art [1] on frequency referencing and frequency error free systems such as Phase Lock Loop (OPLL) and optical injection phase lock loop (OIPLL). The previously described systems offer a way to reference the output of the tuneable laser to a master frequency which could be provided by an optical frequency comb generator (OFCG). However in that work the tuneable laser was used with a temperature controller since the OIPLL provides stable locking only for a range of 5 degrees C. This invention in combination with either the OPLL or OIPLL scheme will provide a zero frequency error source, which can be used effectively in WDM and dense WDM (DWDM) systems, as the tuneable lasers will be coolerless.

Various specific embodiments of the present invention are now described, by way of example only, with reference to the accompanying drawings, in which:

Figure 1. shows typical three and four section tuneable lasers
Figure 2. shows a typical tuneability map for a four section laser at a fixed temperature
Figure 3. shows a typical temperature dependence at a fixed wavelength for the grating section currents of a four section laser (SSG-DBR)
Figure 4. shows a simple scheme to control the output wavelength as a function of the chip temperature for a three or a four section laser
Figure 5. shows the inclusion of the control scheme into a phase lock loop scheme to give a referenced optical frequency output without any temperature control.
Figure 6. shows the inclusion of the control scheme into an optical injection phase lock loop to give a referenced optical frequency output without any temperature control.

This invention discloses a novel technique to achieve tuneable laser operation at any desired optical frequency without the need for laser temperature control. This technique is based on a simple scheme including a thermal sensor and a current/voltage control

system. The invention also discloses a high performance frequency error free optical source eliminating the need for temperature control by combining the disclosed technique with prior work on optical injection phase lock loop systems.

A typical tuneable laser as shown in Figure 1 comprises three or four sections. (1) is the gain section (2) is the phase section (3) and (4) are the main tuning sections. The current on (1) controls the output power, on (2) control the length of the effective Fabry-Perot cavity to adjust to the exact longitudinal mode needed, the currents/voltages on (3) and (4) adjust the wavelength to that required. A three section laser may omit one of the tuning (3), (4) or the phase control sections (2) and in a simple DBR laser, one of the tuning sections. A typical four sections laser tuneable output is represented in Figure 2. One can see the different region of tuneability over a continuous shift of the longitudinal mode. Tuning ranges of over 40 nm in wavelength are obtained for typical four sections lasers.

When the temperature of the chip changes, the output wavelength of the laser changes. For a laser with one grating section the output wavelength will change linearly with the temperature at a rate of approximately 0.1nm/degree C, the variation being continuous if there is no other reflector forming part of the lasing cavity or discontinuous if there is such a reflector. The output wavelength also changes linearly with the current/voltage applied to the grating section. For a laser with two grating sections the output wavelength still changes linearly with the chip temperature at the same rate of approximately 0.1 nm/ degree C. However, this time the wavelength is linked with the grating section currents/voltages by the map shown in Figure 2, but the mode jump boundaries (where the wavelength changes are large) of the mapping do not change, meaning that the zone of stable longitudinal mode (no mode jump) are unchanged with the chip temperature. An important feature of this invention is the use of this property to simplify the computation of the required current/voltage changes to give the required wavelength independently of the laser temperature. To be more precise, as these zones are represented by almost linear areas going from low slope to high slope, the program will first determine in which zone the laser is operating by reading the current/voltage applied to the tuning sections then slope coefficients will be assigned to determine the variation of both currents with the temperature knowing that the

wavelength will change at an approximate rate of 0.1 nm/degree C. At that point the program will just read the laser temperature and change the current/voltage applied to the tuning sections using the slope coefficients assigned previously. This will give, for a given wavelength, an interdependence as seen in the example of Figure 3.

The system for laser frequency control shown in Figure 4 includes a thermal sensor (5) (often included in the laser package) and a microprocessor (6) or analogue controller to derive control currents/voltages for the laser based on the sensed temperature and required wavelength. To be more specific, in this invention, the controller outputs will depend on the correction needed. For a four section laser diode, the correction could be a program based on the linear dependence between wavelength and temperature and the mapping of wavelength dependence for the two tuning section currents/voltages. This could be associated with filtering to remove any rapidly changing signal (the temperature changes are usually slow (μs) in time). For single tuning section laser the controller uses the slopes of the wavelength-temperature-current/voltage characteristics and a filter could be added to remove any rapidly changing signal.

Figure 5 shows the association of the wavelength control and the OPLL to obtain a frequency referenced laser. The OPLL system comprise a coupler (7) to take part of the output of the slave laser, a master source Optical Frequency Comb Generator (OFCG) (8), which is driven by a microwave reference source (9). The outputs of the master laser and part of the output of the slave laser are combined in a coupler (10) and then detected by a photodiode (11). The resulting heterodyne signal is then amplified (12) and sent to a mixer (13), which also receives the microwave reference (9) signal with phased matched by a delay line (14). The resultant signal is then send to the control circuit (15) which will feed the slave laser current/voltage source. The slave laser will be the coolerless wavelength control system described previously. Such systems will provide output frequencies exactly determined by the reference signals and the master comb generator can feed a multi-coolerless source system (only the master laser needs to be stable with temperature).

Figure 6 shows the association of the wavelength control system and the OIPLL to obtain a frequency-referenced laser without the phase lock loop delay restrictions of the

previously described system. The OIPLL comprises an OIL (optical injection locked) laser plus a phase lock loop as described above. In the OIL the output of the master goes to an optical circulator (16) to be sent to the slave laser (for the optical injection). The output of the slave laser (combined with part of the output of the master laser) goes back to the circulator. The output of the circulator is then sent to a coupler (7). The low power output from the coupler is then sent to the PLL system described previously. Such a system provides a highly stable referenced laser with fast locking and coolerless operation.

[1] UK Application No. 0113911.2, [redacted] "Optical Frequency Synthesizer"

CLAIMS

1. Tuneable laser apparatus without closed loop temperature control comprising:
   a. A tuneable laser diode
   b. A thermal sensor
   c. A controller to control the currents or voltages of the grating or other tuning section(s). This controller will adjust these currents or voltages based on the dependence of output frequency on temperature and section currents/voltage to keep the output wavelength at the wanted value whatever the chip temperature is (over the operational temperature range).

2. Apparatus as claimed in claim 1, but including a low pass filter to remove the rapidly changing signals in the control currents or voltages.

3. Apparatus as claimed in claim 1, but the laser is a Distributed Bragg Reflector (DBR) tuneable laser diode.

4. Apparatus as claimed in claim 1, but the laser is a Distributed Feed Back (DFB) tuneable laser diode.

5. Apparatus as claimed in claim 1, but the laser is a Sampled Grating Distributed Bragg Reflector (SG-DBR) tuneable laser diode and the controller includes a processor programmed to follow the tuneability mapping of the two or more tuning section currents or voltages, and feeds the control signals to those sections.

6. Apparatus as claimed in claim 1, but the laser is a Super Structure Grating Distributed Bragg Reflector (SSG-DBR), tuneable laser diode and the controller includes a processor programmed to follow the tuneability mapping of the two or more tuning section currents or voltages, and feeds the control signals to those sections.

7. Apparatus as claimed in claim 1, but the laser is a vertical cavity filter laser and the controller includes a processor programmed to follow the tuneability mapping of the

two or more tuning section currents or voltages, and feeds the control signals to those sections.

8. Apparatus as claimed in claim 5 and a low pass filter is added in the control loop to remove the rapidely changing signals in the control currents or voltages.

9. Apparatus as claimed in claim 6 and a low pass filter is added in the control loop to remove the rapidely changing signals in the control currents or voltages.

10. Apparatus as claimed in claim 7 and a low pass filter is added in the control loop to remove the rapidely changing signals in the control currents or voltages.

11. Apparatus as claimed in claim 1 but the coolerless system is associated with an optical phase lock loop (OPLL) to provide a frequency referenced coolerless laser diode.

12. Apparatus as claimed in claim 1 but the coolerless system is associated with an optical injection phase lock loop system (OIPLL) to provide a frequency referenced coolerless laser diode.

ABSTRACT

This invention describes a technique and apparatus to use any tuneable laser to generate specified output frequency without controlling the temperature.

This technique only involves a thermal sensor and a control loop to determine the current(s) or voltage(s) applied to the grating or tuning section(s) to obtain the required wavelength.

That control loop can be implemented using a programmed microprocessor, an amplifier and a low pass filter.